Response of Herbaceous Perennials to Growth Retardants Applied at Different Developmental Stages when Grown Under Night-Interrupted Lighting Outdoors in the Southern United States[1]

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Abstract

A study was conducted in 2004 and 2005 to determine how 'Early Sunrise' coreopsis (*Coreopsis grandiflora* Hogg ex Sweet. 'Early Sunrise'), 'Moonbeam' coreopsis (*Coreopsis verticillata* L. 'Moonbeam') and 'Goldsturm' rudbeckia (*Rudbeckia fulgida* Aiton 'Goldsturm') responded to two plant growth retardants applied at three stages of plant development (SOD) when plants were exposed to night-interrupted lighting (NIL) while grown outdoors under nursery conditions in the southern United States. With few exceptions, height of all species was suppressed by 2 weeks after first treatment (WAT) compared to NIL only, regardless of whether 5000 ppm B-Nine or 20 ppm Sumagic was applied at the beginning of a period of rapid shoot elongation (SOD 2) or 2 weeks prior to (SOD 1) or following this stage (SOD 3), and continued throughout the plants' vegetative phase, although the level of suppression varied with SOD and PGR. Applying either PGR at SOD 2, when rapid shoot elongation first began, was most effective in suppressing vegetative height of 'Early Sunrise' coreopsis and 'Goldsturm' rudbeckia, whereas vegetative height suppression of 'Moonbeam' coreopsis was not affected by SOD when Sumagic was applied, but suppression was greatest when B-Nine was applied at SOD 1, two weeks before rapid shoot elongation began. 'Early Sunrise' coreopsis and 'Goldsturm' rudbeckia were shortest at first flower when PGRs were applied at SOD 2 and SOD 3, respectively, but plant height of 'Moonbeam' coreopsis at first flower was not affected by SOD. Where differences in height suppression occurred at first flower, B-Nine was more effective than Sumagic. Plant SOD when PGRs were applied had no effect on flowering or plant quality of 'Moonbeam' coreopsis and minimal effect on 'Early Sunrise' coreopsis or 'Goldsturm' rudbeckia.

Index words: flower induction, long-day plant, growth regulator, container production, nursery production.

Species used in this study: 'Goldsturm' rudbeckia (*Rudbeckia fulgida* Ait. 'Goldsturm'); 'Moonbeam' coreopsis (*Coreopsis verticillata* L. 'Moonbeam'), and 'Early Sunrise' coreopsis (*Coreopsis grandiflora* Hogg ex Sweet. 'Early Sunrise').

Growth retardants used in this study: B-Nine (daminozide) [butanedioic acid mono (2,2-dimethylhydrazide)] and Sumagic (uniconazole-P) [(E)(S)-1(4-chlorophenyl)4,4-dimethyl-2(1,2,4-triazol-1-yl) pent-1-ene-3-ol].

Significance to the Nursery Industry

Long-day herbaceous perennials like 'Moonbeam' coreopsis (*Coreopsis verticillata* ('Moonbeam'), 'Early Sunrise' coreopsis (*Coreopsis grandiflora* 'Early Sunrise'), and 'Goldsturm' rudbeckia (*Rudbeckia fulgida* 'Goldsturm') can be forced to flower out-of-season under greenhouse conditions by manipulating temperature and photoperiod. Growers in the southern United States have a similar opportunity for early forcing without adversely affecting flower and flower bud counts by exposing plants to night-interrupted lighting (NIL) outdoors from 10 p.m. to 2 a.m. However, NIL using incandescent lamps can promote excessive shoot elongation. A common recommendation is to apply a plant growth retardant (PGR) when plants begin a period of rapid shoot elongation. While PGR application at this stage can be effective, it may not be as effective as application earlier or later, dependent upon species, PGR, concentration, timing of applications, and marketing stage. Stage of plant development when a PGR is applied is just one factor in managing plant height. Fortunately for the grower of at least the three species tested, plant height growth was suppressed and high quality plants resulted, regardless of whether PGRs were applied when plants began to elongate rapidly or two weeks before or after this period.

Introduction

Under natural short days (SDs), night-interrupted lighting (NIL) using incandescent lamps from 10:00 p.m. to 2:00 a.m. generally is recommended to induce flowering of long-day plants (LDPs) (2, 3, 8), including the qualitative LDPs, 'Moonbeam' coreopsis (*Coreopsis verticillata* 'Moonbeam') (8), 'Early Sunrise' coreopsis (*Coreopsis grandiflora* 'Early Sunrise') (3, 8), and 'Goldsturm' rudbeckia (*Rudbeckia fulgida* 'Goldsturm') (18). While the above cited photoperiod research was conducted in greenhouses or in growth chambers under climate controlled conditions, similar responses were reported in LDPs grown outdoors under nursery conditions in the southeastern United States where environment control was lacking (10, 12). Coastal states in the South, primarily in USDA hardiness zone 8, experience cool nights and mild days in late winter that provide ideal conditions for growing many herbaceous perennials. In particular, vegetative shoots typically begin emerging from crowns in February, long before the arrival of natural long days. When NIL was initiated outdoors on February 1, February 15, March 1, and March 15 and continued until visible floral development, flowering of 'Goldsturm' rudbeckia was accelerated by 26 to 46 days in 1999 and by 51 to 75 days in 2000 when compared to plants grown under a natural photoperiod (NP) (10). Night-interrupted lighting accelerated time to flower and increased

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flower counts of ‘Moonbeam’ coreopsis by 7 to 36 days and 20 to 244% and of ‘Early Sunrise’ coreopsis by 3 to 20 days and 26 to 64%, respectively (12). However, ‘Goldsturm’ rudbeckia grown under NIL was 18 to 23% (1999) and 48 to 52% (2000) taller than plants under natural photoperiods (NP) at anthesis and plant quality ratings were lower in both years. Similarly, ‘Moonbeam’ and ‘Early Sunrise’ coreopsis under NIL were up to 155 and 46%, respectively, taller than plants under NP.

Plant growth retardants (PGRs), including B-Nine (daminozide), B-Nine/Cycocel (chlormequat chloride) mixes, Bonzi (paclobutrazol), and Sumagic (uniconazole), are frequently used to control the growth of horticultural crops during greenhouse production (6, 13, 17). However, efficacy was reduced when PGRs were applied outdoors under nursery conditions as compared to in a greenhouse (7). Yuan et al. (18) reported that ‘Goldsturm’ rudbeckia was too tall when grown in 10.2 or 15.2 cm (4 or 6 in) pots in a greenhouse, and that A-Rest (ancymidol), B-Nine, Bonzi, and Cycocel only slightly reduced plant height, although concentrations applied were not given. Two applications of B-Nine at 2500 to 7500 ppm applied one week apart and two and three weeks after potting of ‘Moonbeam’ coreopsis and ‘Goldsturm’ rudbeckia, respectively, were effective in suppressing plant height during greenhouse production, while tank-mixes of 2500 to 7500 ppm B-Nine/1000 to 2000 ppm Cycocel were less effective (1).

Numerous factors affect a plant’s response to a PGR, including application timing or stage of plant development (9, 15, 16), and most labels recommend conducting trials on a small number of plants under actual use conditions to determine appropriate rates and timing for crops not on the label. In much of the published literature, PGRs were applied based on the time after some event, usually potting, and stage of plant development was not often stated (1, 4, 6, 7, 13). Latimer and Scoggins (14) recommended applying PGRs to herbaceous perennials just prior to rapid shoot elongation, a stage often difficult to determine accurately. When PGRs were applied outdoors under NIL in a nursery setting, two applications of 2500 to 7500 ppm B-Nine, applied when shoots began to elongate rapidly, were ineffective in controlling plant height of ‘Goldsturm’ rudbeckia or ‘Moonbeam’ coreopsis (11). In contrast, when three applications of 2500, 5000, or 7500 ppm B-Nine or a single application of 20, 40, or 60 ppm Sumagic were made the following year beginning when shoots began to elongate under NIL, the higher two concentrations of both PGRs suppressed height of both cultivars to the level of plants grown under natural photoperiod. The effects of PGR applications at other times or stages of plant development were not determined, but may have provided different results. The objective of this study was to determine the effects of PGR timing on vegetative growth and flowering of ‘Moonbeam’ and ‘Early Sunrise’ coreopsis and ‘Goldsturm’ rudbeckia exposed to NIL when grown outdoors under nursery conditions in the southern U.S.

Materials and Methods

Unbranched rooted cuttings of ‘Moonbeam’ coreopsis (*Coreopsis verticillata* ‘Moonbeam’) and ‘Goldsturm’ rudbeckia (*Rudbeckia fulgida* ‘Goldsturm’) from 72-cell flats (Green Leaf Perennials, Lancaster, PA) were transplanted on December 17, 2003, into 2.8 liter (#1 trade) pots containing a milled pine bark:peat (3:1, by vol) substrate. The growth medium was amended per m^3 (yd^3) with 8.3 kg (14 lb) 17N-3P-10K (Osmocote 17-7-12, The Scotts Company, Marysville, OH/Everris NA, Dublin, OH since 2011), 3.6 kg (6 lb) dolomitic limestone, 1.2 kg (2 lb) gypsum, and 0.9 kg (1.5 lb) Micromax (The Scotts Company/Everris NA). ‘Moonbeam’ coreopsis plants were 1 cm (0.4 in) tall and 3 cm (1.2 in) wide and rudbeckia were 1 cm (0.4 in) tall and 5 cm (2.0 in) wide when transplanted. ‘Early Sunrise’ coreopsis (*Coreopsis grandiflora* ‘Early Sunrise’) in 72-cell flats (Green Leaf Perennials) were held in an unheated greenhouse for 3 weeks to promote growth before being transplanted on January 24, 2004, into the same substrate and containers; at that time they were 4 cm (1.6 in) tall and 15 cm (6.0 in) wide. Plants were grown pot-to-pot outdoors in full sun through the winter under NPs at the Ornamental Horticulture Research Center, Mobile, AL (USDA cold hardiness zone 8b; 30.7° north latitude, 88.2° west longitude), and were watered as needed from overhead impact sprinklers. Pots were respaced as plants grew so that plant canopies did not overlap. Plants were covered with white polyethylene from December 21–23, 2003, due to predicted temperatures below –6.7C (20F). Low-temperature protection was not necessary at any other time during the study.

A night-interrupted lighting block was established outdoors in the nursery area to provide a minimum of 10 foot-candles of light from 10:00 p.m. to 2:00 a.m. Sixty watt incandescent lamps were spaced 1.3 m (4 ft) on center within rows and 1.5 m (5 ft) between rows. Lamps were placed 1.2 m (4 ft) above ground level and 1.1 m (3.5 ft) or less above plants. Photosynthetically active radiation at plant height, as measured with a LI-COR LI-6400 steady-state porometer (LI-COR Biosciences, Lincoln, NE), averaged 1.5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ over the NIL area. Space limitations prevented the replication of the lighting set-up. On February 1, 2004, 70 uniform plants of each cultivar were moved under NIL, and 10 uniform plants of each cultivar remained as unlighted controls. Cultivars were treated as separate experiments. A black plastic curtain separated plants receiving NIL and unlighted control plants to a height of 1.8 m (6 ft) to prevent light leakage, and was far enough from all plants to provide no shading.

Treatments consisted of foliar sprays of 5000 ppm B-Nine or 20 ppm Sumagic applied at three times, based on stage of plant development (SOD), to plants under NIL, plus a NIL standard and a NP control, each replicated with 10 single plants. The first and third timings corresponded to two weeks before and after the initiation of rapid shoot elongation, while the second timing was during the initial rapid shoot elongation out of the rosette stage. Timing of the first application to plants in the rosette stage was based on previous research with these species exposed to NIL under similar cultural and environmental conditions (10, 11, 12). PGR treatments were applied to ‘Early Sunrise’ coreopsis only once at each SOD due to its natural early spring flowering and rapid flowering response to NIL (12). Sumagic was applied once to the other two species at each SOD, whereas, B-Nine was applied twice to ‘Moonbeam’ coreopsis and three times to ‘Goldsturm’ rudbeckia at 7- to 14-day intervals. Application concentrations and numbers were based on previous research with these species under similar cultural and environmental conditions (11).

Treatments were applied to plants of ‘Early Sunrise’ coreopsis at SOD 1, 2, and 3 on February 24, March 8, and

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March 22, 2004, when height of plants under NIL and NP averaged 7.8 and 4.7 cm (3.1 and 1.9 in), 17.6 and 7.1 cm (6.9 and 2.8 in), and 24.2 and 14.6 cm (9.5 and 5.7 in), respectively. Treatments were applied to 'Goldsturm' rudbeckia and 'Moonbeam' coreopsis at SOD 1, 2, and 3 on March 8, March 22, and April 6, 2004, with additional applications of B-Nine made to both cultivars at 7- to 14-day intervals. At SOD 1, 2, and 3, height of 'Goldsturm' rudbeckia under NIL and NP averaged 12.1 and 2.5 cm (4.8 and 1.0 in), 16.7 and 2.9 cm (6.6 and 1.1 in), and 24.2 and 4.7 cm (9.5 in and 1.9 in), respectively, and plants of 'Moonbeam' coreopsis averaged 5.7 and 2.2 cm (2.2 and 0.9 in), 19.8 and 2.4 cm (7.8 and 0.9 in), and 33.3 and 2.6 cm (13.1 and 1.0 in), respectively. PGR treatments were applied at 0.2 liters·m^{-2} (equivalent to 2 qt·100 ft^{-2}) using a CO_2 sprayer with a flat fan spray nozzle (TeeJet 8003VS, Bellspray, Inc., Opelousas, LA) at 310 kPa (45 psi). Temperature and relative humidity were 12C (58F) and 94%, 22C (72F) and 42%, 16C (61F) and 54%, and 24C (76F) and 45% when treatments were applied to 'Early Sunrise' coreopsis at SOD 1, 2, and 3 and to the other two cultivars at SOD 3, respectively. Plants were not exposed to irrigation or rainfall for at least 12 hours after treatment.

Plant height was measured every 2 weeks beginning at first treatment application and continued until plants of that cultivar first came into flower. The dates of the first visible floral bud and first fully-opened flower (inflorescence) were recorded; first flower was considered when ray flowers on the first inflorescence were fully reflexed. At first flower, flower and flower bud counts (except on 'Moonbeam' coreopsis), plant height from the substrate surface to the uppermost plant part, and quality rating were determined. Rather than actual flower and flower bud counts, flowering of 'Moonbeam' coreopsis was rated on the following scale: 1 = 0, 2 = 1 to 50, 3 = 51 to 100, 4 = 101 to 150, or 5 = >150 flowers and flower buds per plant. Quality rating varied slightly among the three cultivars but in general was as follows: 1 = dead; 2 = chlorotic foliage, excessive stem elongation or small plant, minimal flowers; 3 = light green foliage, excessive stem elongation or small plant, reduced flower count as compared to '4'; 4 = medium green foliage, less stem elongation and a larger plant than those rated '3', adequate flowers and flower buds; and 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower ratings. The quality rating scale, while subjective, was the consensus of four individuals and represented an effort to quantify and rank in one rating several factors that impacted overall plant quality: compactness, fullness, foliar color and flowering. All ratings were assigned by one person.

The experiment was repeated the following winter using similar methodology except as noted below. Transplants of the two cultivars were repotted on December 16, 2004. Treatments were applied to plants of 'Early Sunrise' coreopsis at SOD 1, 2, and 3 on February 21, March 7, and March 21, 2005, when height of plants under NIL and NP averaged 10.6 and 7.1 cm (3.1 and 1.9 in), 17.2 and 8.7 cm (6.9 and 2.8 in), and 25.7 and 13.4 cm (9.5 and 5.7 in), respectively. Treatments were applied to 'Goldsturm' rudbeckia and 'Moonbeam' coreopsis at SOD 1, 2, and 3 on March 7, March 21, and April 4, 2004, with additional applications of B-Nine made to both cultivars at 7- to 14-day intervals. At SOD 1, 2, and 3, height of 'Goldsturm' rudbeckia under NIL and NP averaged 12.3 and 2.7 cm (4.8 and 1.1 in), 17.6 and 3.6 cm (6.9 and 1.4 in), and 29.3 and 5.3 cm (11.5 and 1.9 in), respectively, and plants of 'Moonbeam' coreopsis averaged 3.7 and 1.9 cm (1.5 and 0.7 in), 7.8 and 2.1 cm (3.1 and 0.8 in), and 15.8 and 3.0 cm (6.2 and 1.2 in), respectively. Temperature and relative humidity were 25C (77F) and 79%, 26C (79F) and 73%, 22C (72F) and 77%, and 21C (70F) and 68% when treatments were applied to 'Early Sunrise' coreopsis at SOD 1, 2, and 3 and to the other two cultivars at SOD 3, respectively.

In both experiments, an analysis of variance was performed on all data using PROC GLIMMIX in SAS version 9.2 (SAS Institute, Cary, NC). The two experiments in the study were completely randomized designs with the two years (experiments) included in the model as a random variable. Where residual plots indicated heterogeneous variance, a random statement with the group option was used in the analysis. For plant height recorded every two weeks from the first PGR application, a three-way factorial treatment arrangement of recording date, PGR and SOD was used. Single degree of freedom orthogonal contrasts were used to test linear and quadratic trends over stage of development and recording date, and paired comparison contrasts were used to compare these treatments to NIL and NP. For data recorded at the time of first open flower, a two-way factorial treatment arrangement of PGR and SOD was used. Single degree of freedom orthogonal contrasts were used to test linear and quadratic trends over stage of development, and paired comparison contrasts were used to compare PGRs at each SOD and PGR treatments to NIL and to NP. Quality ratings and flower number ratings for 'Moonbeam' coreopsis were analyzed using the multinomial probability distribution with a cumulative logit link; treatment medians are presented in the tables. Otherwise, least squares means are presented. All significances were at $\alpha = 0.05$.

Results and Discussion

Average monthly temperatures in Mobile, AL, ranged from 2.4C (4.4F) below normal in February 2004 to 1.1C (1.9F) above normal in March 2004, and from 1.8C (3.2F) above normal in February 2005 to 0.9C (1.6F) below normal in April 2005 (Table 1). Over the February to June duration of the study, average temperatures were 0.4C (0.6F) below normal in 2004 and normal in 2005. No extreme temperatures occurred during this study and monthly averages closely followed the 30-year average.

'Early Sunrise' coreopsis. Beginning with the first height measurements 3½ weeks after the initiation of LDs and

Table 1. Average monthly temperatures and departures from normal for Mobile, AL, from February through June 2004 and 2005.

Month	Temperature [C (F)][z] 2004	Departure	2005	Departure
February	9.4 (48.9)	–2.4 (–4.4)	13.7 (56.7)	1.8 (3.2)
March	16.6 (61.9)	1.1 (1.9)	14.9 (58.9)	–0.7 (–1.3)
April	18.1 (64.5)	–0.6 (–1.0)	18.1 (64.5)	–0.9 (–1.6)
May	23.1 (73.5)	0.1 (0.2)	22.8 (73.1)	–0.2 (–0.4)
June	26.2 (79.1)	0.0 (0.0)	26.2 (79.2)	–0.1 (–0.1)

[z]Temperatures measured 1.5 m (5 ft) above the ground.

[y]Departures from normal (30-year average); weather data provided by the NOAA, National Climatic Data Center.

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Table 2. Effects of plant growth retardants applied at different stages of development on plant height (cm) over time of summer-blooming herbaceous perennials grown under night-interrupted lighting and nursery conditions in the southern United States in 2004 and 2005.[z]

WAT[w]	B-Nine[y] Stage of development[x] 1	2	3	Sign.[v]	Sumagic Stage of development 1	2	3	Sign.	NIL[u]	NP[u]
Coreopsis grandiflora 'Early Sunrise'										
0	9.3ns*[t]	9.2ns*	9.3ns*	NS	9.0*	9.2*	10.1*	NS	9.8*	5.8
2	14.9ns**	17.2ns*	17.5ns*	—[s]	15.8*	17.6*	17.7*	—	17.4*	7.8
4	20.2ns**	20.4ns**	24.3ns*	—	19.4**	21.1**	25.5*	—	25.2*	14.0
6	27.7b**	24.9ns**	29.9ns**	Q***	30.6a**	25.1**	31.2**	Q***	35.4*	19.5
Sign.	L***	Q*	L***		Q***	Q**	L***			
Coreopsis verticillata 'Moonbeam'										
0	4.9ns*	5.3ns*	5.7ns*	NS	4.5*	5.4*	5.3*	NS	4.2*	2.1
2	6.6ns**	14.4ns*	12.5ns*	—	7.4**	13.2*	13.0*	—	12.5*	1.9
4	9.9b**	19.6ns**	23.7ns*	—	18.2a**	19.1**	5.8*	—	25.2*	1.5
6	20.3b**	23.5ns**	26.0b**	L*	29.0a**	28.0**	31.4a*	NS	34.0*	5.6
Sign.	Q**	Q**	Q**		Q*	L***	Q*			
Rudbeckia fulgida 'Goldsturm'										
0	12.1ns*	10.9ns*	11.4ns*	NS	12.4*	11.4*	11.5*	NS	11.3*	2.6
2	10.6ns**	17.3ns*	18.0ns*	—	11.9**	17.0*	17.0*	—	16.7*	3.2
4	13.7b**	19.6ns**	27.0ns*	—	19.8a**	19.0**	26.5*	—	27.8*	5.0
6	23.1b**	22.1b**	29.4b**	Q***	30.0a**	26.6a**	32.8a**	Q***	36.2*	8.9
8	31.5b**	29.8b**	31.7b**	Q*	39.6a**	36.6a**	37.6a**	Q*	46.3*	13.0
Sign.	Q***	L***	Q***		Q***	Q***	L***			

[z]The plant growth retardant by stage of development by weeks after first plant growth retardant application interaction was significant at α = 0.05. Years were analyzed as a random variable.

[y]B-Nine (daminozide) was applied at 5,000 ppm and Sumagic (uniconazole) was applied at 20 ppm.

[x]Stage of development 2 was when each species initiated vigorous growth while stages 1 and 3 were 2 weeks before and after, respectively.

[w]WAT = weeks after treatment of plants at SOD 1.

[v]Non-significant (NS) or significant (Sign.) linear (L) or quadratic (Q) response over stage of development (rows) and WAT (columns) within plant growth retardant and species using orthogonal contrasts at α = 0.05 (*), 0.01 (**), or 0.001 (***).

[u]NIL = night-interrupted lighting; NP = natural photoperiod.

[t]Un-shaded plant heights were recorded before plant growth retardants were applied. Least squares means comparisons between plant growth retardant treatments (letters in rows, ns = non-significant) using paired contrasts at α = 0.05. Plant growth retardant or NIL means followed by an asterisk are different from natural photoperiod or followed by two asterisks are different from night-interrupted lighting and natural photoperiod means.

[s]Treatments not yet applied to plants at SOD 2 and SOD 3 until 2 and 4 weeks, respectively, after application to plants at SOD 1; therefore, trend analysis was not performed.

continuing until the last vegetative height measurements 6 weeks later, heights of 'Early Sunrise' coreopsis exposed to NIL were greater than those of plants under NP, regardless of PGR or SOD treatments (Table 2). This effect has been noted in previous studies (10, 11, 12) and is an example of the bolting response of LD plants under photo-inductive conditions (2, 3, 8). Height of plants treated with B-Nine, but not Sumagic, at SOD 1 was suppressed 14%, compared to plants in the NIL only treatment, as early as 2 weeks after treatment (WAT). At 4 WAT (SOD 1) and 2 WAT (SOD 2) plants treated with B-Nine were about 20% shorter than those under NIL only, while those treated with Sumagic were 23% (SOD 1) and 16% (SOD 2) shorter. Heights of plants 6, 4, and 2 WAT at SOD 1, 2, and 3, respectively, with either PGR were 12 to 30% lower than plants under NIL, with the shortest plants treated at SOD 2 (29–30% reduction) and the tallest treated at SOD 3 (12–16% reduction), a quadratic trend. Similarly, at full flower plants treated at SOD 2 were the shortest, 24% shorter than plants under NIL only, while plants treated with either PGR at SOD 1 and 3 were only 7 and 16% shorter than plants under NIL only (Table 3). Plants treated at SOD 2 also were the only ones similar in height to those under NP, while plants treated at SOD 1 and 2 and plants under NIL only were 21, 9, and 29% taller, respectively, than plants under NP. With one exception, plants treated with the two PGRs at the same SOD were similar in height, regardless of the time after treatment (Table 2). These height measurements indicate that applying 5000 ppm B-Nine or 20 ppm Sumagic to 'Early Sunrise' coreopsis when shoots first begin to elongate rapidly (SOD 2) results in greater height suppression than applying either PGR 2 weeks prior to or when plants are well into a period of rapid shoot elongation and are consistent with recommendations made by Latimer and Scoggins (14).

NIL accelerated time to visible floral bud (DVB) by 12 days compared to NP, while PGR application delayed DVB by 2 days compared to NIL. Similarly, NIL accelerated days to full flower (DTF) by 14 days compared to NP. In

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Table 3. **Effects of plant growth retardants applied at different stages of development on growth and flowering of *Coreopsis grandiflora* 'Early Sunrise' and grown under night-interrupted lighting and nursery conditions in the southern United States in 2004 and 2005.[z]**

Trt[y]	DVB[x]	QR[w]	Trt[v]	DTF[u]	SOD[t]	Height (cm)	Flower count
All PGRs[s]	46b[r]	4.75a	B-Nine[q]	71a*+[p]	1	39.2**	43*
NIL[o]	44c	4.0b	Sumagic	68b*+	2	32.0+	36*+
NP[o]	56a	4.5a	NIL	65*	3	35.1*+	37*+
			NP	79	Sign.[n]	Q***	Q*
					NIL	42.0*	43*
					NP	32.3	31

[z]The treatment design was a factorial of plant growth retardant and stage of development with night-interrupted lighting and natural photoperiod controls. Years were analyzed as a random variable.

[y]No differences were found among the plant growth retardant treatments at α = 0.05.

[x]DVB = days to visible bud.

[w]Quality rating (QR): 1 = dead; 2 = chlorotic foliage, excessive stem elongation or small plant, minimal flowers; 3 = light green foliage, excessive stem elongation or small plant, reduced flower count as compared to '4'; 4 = medium green foliage, less stem elongation and a larger plant than those rated '3', adequate flowers and flower buds; and 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower ratings. Median values are reported.

[v]Only the main effect plant growth retardant was significant α = 0.05.

[u]DTF = days to flower.

[t]Stage of development (SOD) 2 was when each species initiated vigorous growth while stages 1 and 3 were 2 weeks before and after, respectively. Only the main effect stage of development was significant α = 0.05.

[s]PGR = plant growth retardant.

[r]Least squares means for all growth retardant treatments were compared to those for night-interrupted lighting and natural photoperiod using paired contrasts at α = 0.05.

[q]B-Nine (daminozide) was applied at 5,000 ppm and Sumagic (uniconazole) was applied at 20 ppm.

[p]Least squares means for the two growth retardants were compared using the main effect F-test at α = 0.05. Night-interrupted lighting (+) and natural photoperiod (*) were compared to the other treatments using paired contrasts at α = 0.05.

[o]NIL = night-interrupted lighting; NP = natural photoperiod.

[n]Significant (Sign.) quadratic (Q) response over SOD (columns) using orthogonal contrasts at α = 0.05 (*) or 0.001 (***).

contrast, B-Nine delayed flowering 6 days compared to NIL, while Sumagic only delayed flowering 3 days. Delays in flowering of many species have been reported in response to PGRs, particularly B-Nine (1, 4, 5, 13, 17); however, plants treated with either PGR flowered 8 to 11 days before those under NP. Flower counts of plants under NIL, regardless of PGR treatment, were higher than those of plants under NP, although counts of plants treated at SOD 2 or 3 were 15% lower than for plants under NIL. Accelerated flowering and increased flower counts of 'Early Sunrise' coreopsis grown outdoors under NIL concur with the results of a previous study using the same cultivar (12). Quality ratings (QR) of plants in all PGR/SOD treatments were similar and similar to that of plants under NP; however, QR of plants exposed to NIL only was lower, primarily due to plants being taller at first flower.

'Moonbeam' coreopsis. Vegetative height of 'Moonbeam' coreopsis in response to NIL followed a similar pattern to that of 'Early Sunrise' coreopsis (Table 2). Beginning with the first height measurements 5½ weeks after the initiation of NIL and continuing until the last vegetative height measurements 6 weeks later, height of 'Moonbeam' coreopsis exposed to NIL was greater than that of plants under NP, regardless of PGR or SOD treatments. Also similar to 'Early Sunrise' coreopsis, height of 'Moonbeam' coreopsis treated with either PGR, regardless of SOD and compared to plants under NIL only, was suppressed as early as 2 WAT and continued until the last vegetative height measurements were taken 6 WAT (SOD 1), with one exception, the lack of effect of Sumagic applied at SOD 3. Treatment of plants with B-Nine at SOD 1 was most effective in suppressing height growth at 6 WAT, a linear trend, while SOD had little or no effect on vegetative height when Sumagic was applied. Height suppression relative to height of plants under NIL only ranged from 15% for plants 6 WAT with Sumagic at SOD 1 to 61% for plants 4 WAT with B-Nine at SOD 1. In half of the cases where one or both of the PGRs suppressed vegetative height growth relative to that of NIL only, suppression from the two PGRs was similar. However, in the other cases plants treated with B-Nine were 16 to 46% shorter than those treated with Sumagic. At first flower, height of plants grown under NIL only were 79% taller than those under NP, while plants treated were B-Nine and Sumagic under NIL were 32 and 46%, respectively, taller, and plants treated with B-Nine were 10% shorter than those treated with Sumagic (Table 4). These levels of height suppression at first flower are consistent with an earlier study using the same cultivar and PGRs outdoors under nursery conditions and NIL (11). The different effectiveness of the two PGRs in suppressing height growth was expected due to numerous factors affective PGR activity, including species. For example, B-Nine at 5000 ppm effectively suppressed height growth of salvia (*Salvia ×sylvestris* 'May Night') but not scabiosa (*Scabiosa columbaria* 'Butterfly Blue'), while 20 ppm Sumagic had the opposite effect on the two species (4). Application of B-Nine, but not Sumagic, prior to rapid shoot elongation resulted in the shortest vegetative plants, suggesting that if plants are to be marketed prior to flowering, early PGR application (SOD 1) is likely to be more effective. However, in contrast to vegetative heights and results with 'Early Sunrise' coreopsis, SOD effects on plant height present during vegetative growth were no longer evident at first flower, suggesting that applying either of these PGR between 2 weeks before and after the beginning of rapid shoot elongation is likely to have a similar effect on plant height at first flower.

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Table 4. Effects of plant growth retardants applied at different stages of development on growth and flowering of *Coreopsis verticillata* 'Moonbeam' and grown under night-interrupted lighting and nursery conditions in the southern United States in 2004 and 2005.[z]

Trt[y]	Days to visible bud	Days to flower	Flower rating[x]	Quality rating[w]	Trt[v]	Height (cm)
All NIL[u]	60b[t]	84b	2.75a	3.75a	B-Nine[s]	29.0b*+[r]
NP[u]	82a	102a	1.5b	3.5b	Sumagic	32.3a*+
					NIL	39.4*
					NP	22.0

[z]The treatment design was a factorial of plant growth retardant and stage of development with night-interrupted lighting and natural photoperiod controls. Years were analyzed as a random variable.

[y]No differences were found among the night-interrupted lighting (NIL) treatments at α = 0.05.

[x]Inflorescence counts were estimated using the scale: 1 = 0, 2 = 50, 3 = 100, 4 = 150 and 5 = 200. Median values are reported.

[w]Quality rating (QR): 1 = dead; 2 = chlorotic foliage, excessive stem elongation or small plant, minimal flowers; 3 = light green foliage, excessive stem elongation or small plant, reduced flower count as compared to '4'; 4 = medium green foliage, less stem elongation and a larger plant than those rated '3', adequate flowers and flower buds; and 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower ratings. Median values are reported.

[v]Only the main effect plant growth retardant was significant α = 0.05.

[u]NIL = night-interrupted lighting; NP = natural photoperiod.

[t]Least squares means for all night-interrupted lighting treatments were compared to those for natural photoperiod using paired contrasts at α = 0.05.

[s]B-Nine (daminozide) was applied at 5,000 ppm and Sumagic (uniconazole) was applied at 20 ppm.

[r]Least squares means for the two growth retardants were compared using the main effect F-test at α = 0.05. Night-interrupted lighting (+) and natural photoperiod (*) were compared to the other treatments using paired contrasts at α = 0.05.

Regardless of PGR or SOD treatment, NIL accelerated time to visible bud and first flower by 22 and 18 days, respectively, and increased flower and quality ratings, which agrees with an earlier study in which PGRs were applied to 'Moonbeam' coreopsis grown under similar conditions (11).

'Goldsturm' rudbeckia. Vegetative height growth of 'Goldsturm' rudbeckia, in response to NIL, followed a similar pattern to that of 'Early Sunrise' and 'Moonbeam' coreopsis (Table 2). Beginning with the first height measurements 5½ weeks after the initiation of NIL and continuing until the last vegetative height measurements 8 weeks later, height of 'Goldsturm' rudbeckia exposed to NIL was greater than that of plants under NP, regardless of PGR or SOD treatments (Table 2). Also similar to coreopsis, height suppression, relative to height of plants under NIL but not treated with a PGR, was evident within 2 WAT with both PGRs, regardless of SOD, and continued through the last vegetative height measurements 8 WAT at SOD 1. In the nine cases where both PGRs suppressed vegetative height growth relative to that of NIL only, suppression from the two PGRs was similar in two cases. However, in the other seven cases plants treated with B-Nine were 10 to 31% shorter than those treated with Sumagic. B-Nine at 5000 ppm was applied three times 7 to 14 days apart, whereas 20 ppm Sumagic was applied only once. The effects of SOD on vegetative plant height 6 and 8 WAT at SOD 1 was quadratic with both PGRs, indicating that the shortest plants were those treated at SOD 2, when plants began to elongate rapidly. However, at first flower the response to SOD was linear, indicating that applying PGR treatments at SOD 3 was most effective in suppressing height growth for plants marketed in flower and that the activity of both PGRs applied at SOD 1 and 2 was dissipating (Table 5). In all cases PGR application suppressed plant height at first flower 9 to 31% relative to that of plants grown under NIL only, plants treated with B-Nine at SOD 2 or 3 were 9 to 14% shorter than those under NP, and plants treated with B-Nine were shorter than those treated with Sumagic, regardless of SOD. These results suggest that three applications of 5000 ppm B-Nine begun 2 weeks after rapid shoot elongation and spaced 7 to 14 days apart is more effective in suppressing height growth of 'Goldsturm' rudbeckia marketed in flower than earlier applications or than a single application of 20 ppm Sumagic applied at any of the three tested SODs.

Compared to plants grown under NP, time to visible flower bud was accelerated by 48 to 52 days by NIL, regardless of PGR treatment, and only application of B-Nine at SOD 1 delayed time to visible bud relative to that of plants grown under NIL only (Table 5). Similarly, time to first flower was accelerated by 53 to 59 days by NIL, but was not affected by SOD, indicating a greater effect of NIL on time to visible bud and flower of this later-blooming perennial than on early-blooming long-day perennials like coreopsis. These accelerated times to flower are similar to those previously reported for 'Goldsturm' rudbeckia grown outdoors under NIL (10, 11) and could greatly expand the marketing windows of this cultivar, which typically doesn't flower until late June or July in the lower South. B-Nine delayed flowering by 6 days, relative to plants under NIL only, whereas Sumagic had no effect on days to flower, which agrees with a previous study using these two PGRs on rudbeckia grown outdoors under NIL (11). Compared to plants grown under NP, flower and flower bud counts of plants exposed to NIL, regardless of PGR or SOD treatment, increased 43 to 69%. Quality rating was high for all plants, but higher for plants in all PGR treatments than for plants under NP because of their compact size and greater number of flowers and flower buds, and similar for plants treated with B-Nine and Sumagic, regardless of SOD.

Results of this study indicate that the response of herbaceous perennials to PGRs when grown outdoors under nursery conditions was influenced by stage of plant development, PGR, and species. With few exceptions, B-Nine and Sumagic suppressed height growth of 'Early Sunrise' and 'Moonbeam' coreopsis and 'Goldsturm' rudbeckia within 2 weeks of application, regardless of SOD, and suppression continued through the plants' vegetative phase, although the level of suppression varied with SOD and PGR. Applying either PGR at SOD 2, when rapid shoot elongation first began, was most effective in suppressing vegetative height of 'Early

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Table 5. **Effects of plant growth retardants applied at different stages of development on growth and flowering of *Rudbeckia fulgida* 'Goldsturm' and grown under night-interrupted lighting and nursery conditions in the southern United States in 2004 and 2005.[z]**

	Days to visible bud		Height (cm)		Quality rating[y]				
SOD[x]	B-Nine[w]	Sumagic	B-Nine	Sumagic	B-Nine	Sumagic	Flower count[v]	Trt[u]	DTF[t]
1	75a*+[s]	72b*	46.0b+	50.6a*+	4.5*	4.5*	27*	B-Nine	105ns*+[r]
2	72ns*	71*	40.4b*+	46.7a+	5.0*+	4.5*	27*	Sumagic	100*
3	72ns*	72*	38.1b*+	46.8a+	4.5*	4.5*	23*	NIL[q]	99*
Sign.[p]	L**	NS	L***	L**	Q*	NS	Q*	NP[q]	158
NIL	71*		55.5*		4.0		26*		
NP	123		44.2		4.0		16		

[z]The treatment design was a factorial of plant growth retardant and stage of development with night-interrupted lighting and natural photoperiod controls. Years were analyzed as a random variable.

[y]Quality rating (QR): 1 = dead; 2 = chlorotic foliage, excessive stem elongation or small plant, minimal flowers; 3 = light green foliage, excessive stem elongation or small plant, reduced flower count as compared to '4'; 4 = medium green foliage, less stem elongation and a larger plant than those rated '3', adequate flowers and flower buds; and 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower ratings. Median values are reported.

[x]Stage of development (SOD) 2 was when each species initiated vigorous growth while stages 1 and 3 were 2 weeks before and after, respectively. The interaction of plant growth retardant and stage of development was significant at $\alpha = 0.05$.

[w]B-Nine (daminozide) was applied at 5,000 ppm and Sumagic (uniconazole) was applied at 20 ppm.

[v]Only the main effect stage of development was significant $\alpha = 0.05$.

[u]Only the main effect plant growth retardant was significant $\alpha = 0.05$.

[t]DTF = days to flower.

[s]Least squares means comparisons between the plant growth retardants at each stage of development using paired contrasts at $\alpha = 0.05$. Night-interrupted lighting (+) and natural photoperiod (*) were compared to the plant growth retardant treatments using paired contrasts at $\alpha = 0.05$.

[r]Least squares means for the two growth retardants were compared using the main effect F-test at $\alpha = 0.05$.

[q]NIL = night-interrupted lighting; NP = natural photoperiod.

[p]Non-significant (NS) or significant (Sign.) linear (L) or quadratic (Q) response using orthogonal contrasts at $\alpha = 0.05$ (*), 0.01 (**) or 0.001 (***).

Sunrise' coreopsis and 'Goldsturm' rudbeckia, whereas vegetative height suppression of 'Moonbeam' coreopsis was not affected by the SOD when Sumagic was applied, but was most effective when B-Nine was applied at SOD 1, two weeks before rapid elongation began. The response varied somewhat at first flower: 'Early Sunrise' coreopsis and 'Goldsturm' rudbeckia were shortest when PGRs were applied at SOD 2 and SOD 3, respectively, but plant height of 'Moonbeam' coreopsis was not affected by SOD. The choice of applying 5000 ppm B-Nine and 20 ppm Sumagic one or more times was based on results of a similar study using coreopsis and rudbeckia (11). Results of the current study indicate the effectiveness of the applied dosage in controlling vegetative height growth of three species that normally flower at very different times: early spring ('Early Sunrise' coreopsis), late spring ('Moonbeam' coreopsis), and early to mid-summer ('Goldsturm' rudbeckia) in coastal Alabama. However, these results also suggest that the effects of early application of either PGR to the later-flowering 'Goldsturm' rudbeckia were dissipating by first flower, and plants treated at SOD 1 or 2 would have benefitted from an additional application of either PGR. The same is true for 'Early Sunrise treated at SOD 1, whereas the taller plants treated at SOD 3 support earlier PGR application. Where differences in height suppression occurred at first flower, B-Nine was more effective than Sumagic. Effects of applying PGRs at different SODs on flowering and plant quality were consistent with those from an earlier PGR study outdoors under NIL (11) and again demonstrate the potential of this low-input system in forcing long-day perennials into flower during the peak marketing season. Finally, these results indicate the difficulty in precisely describing when to apply PGRs, and emphasize the importance of grower experience in regulating plant height of a crop throughout production using PGRs.

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